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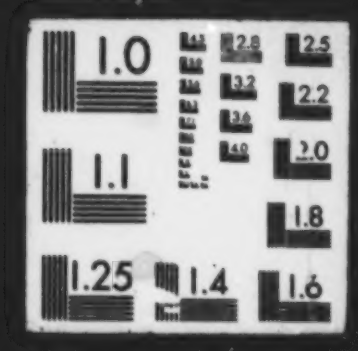

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BACTERIOLOGICAL EFFECTS OF PRIMARY TREATMENT PLANT DISCHARGES AT BREMERTON, WASHINGTON

Federal Water Pollution Control Administration
Portland, Oregon

July 1970

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Bacteriological Effects of Primary Treatment Plant Discharges at Bremerton, Washington

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UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
NORTHWEST REGION

STATE OF WASHINGTON
WATER POLLUTION CONTROL COMMISSION

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BACTERIOLOGICAL EFFECTS OF PRIMARY TREATMENT PLANT DISCHARGES AT BREMERTON, WASHINGTON

State of Washington
Water Pollution Control Commission
Olympia, Washington

United States Department of Interior
Federal Water Pollution Control Administration
Northwest Region
Portland, Oregon

July, 1970

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INTRODUCTION

Statement of Problem

In the Pacific Northwest many water quality problems are associated with the development of maritime areas. High water quality standards have been adopted to protect the water resources of the area for present and future use. The adequacy of existing waste treatment and di_posal systems is being evaluated to insure compliance with these approved standards.

Many communities in Puget Sound presently rely upon primary treatment of their wastes. Water quality standards adopted by the State of Washington (1) state:

> Where existing and new commercial, industrial or domestic wastes discharge to salt water, secondary treatment shall be required unless, after a review of existing data or an engineering study, it can be demonstrated that a lesser degree of treatment will provide for protection of present and future water uses and the preservation or enhancement of existing water quality. In no case, however, will less than primary treatment together with disinfection and adequate outfall be accepted.

In May, 1968, the Washington Water Pollution Control Commission (WPCC) requested Federal Water Pollution Control Administration (FWPCA) concurrence in designating a selected group of Puget Sound municipal waste treatment plants as falling under the category of "acceptable primary treatment" for this exception.

FWPCA approved this request with the condition that evaluations be conducted by 1970 to determine if primary treatment is providing compliance with water quality standards. WPCC and FWPCA have started a program of field evaluations and reviews of existing data to provide the needed information. The first phase of this program was a field survey to evaluate the bacteriological effects of primary treatment plant discharges at Bremerton, Washington.

Objectives

The specific objectives of this study were to answer the following questions for dry weather conditions:

1. What is the general background level and distribution of total coliform bacteria in the waters of Sinclair Inlet and Port Washington Narrows?

2. What effect does the discharge of primary chlorinated effluent through shallow marine outfalls have upon bacteriological water quality of Sinclair Inlet and Port Washington Narrows?

Scope of Study

The study emphasized bacteriological analyses, both in the treatment plants and in the waters of Sinclair Inlet and Port Washington Narrows. Chemical analyses were conducted to aid in defining plant operating characteristics. Field work was done on September 9, 10, and 11, 1969. Literature dealing with chlorination of primary treatment plant effluents was reviewed.

Authority

This study was conducted jointly by the Federal Water Pollution Control Administration and the Washington Pollution Control Commission. Sections 3 (a) and 5 (b) of the Federal Water Pollution Control Act, as amended, authorizes Federal participation in studies of this type.

Acknowledgements

The cooperation and assistance of the City of Bremerton employees, particularly the operating staff at the Manette and Charleston treatment plants, is gratefully acknowledged.

SUMMARY

Findings

1. Twelve sets of duplicate surface-water samples taken above the outfall at Bremerton Plant 2 (Charleston Plant) had a geometric mean total coliform density of 4500 per 100 milliliters (4500/100 ml). Individual values ranged from 130 to 150,000/ml. The standard deviation was 50,000/100 ml.

2. Nine sets of surface-water samples taken above the outfall at Bremerton Plant 1 (Manette Plant) had a geometric mean total coliform density of 550/100 ml. Individual values ranged from 10 to 29,000/100 ml. The standard deviation was 7300/100 ml.

3. Total available chlorine residuals at Plant 2 had a mean value of 0.90 milligrams per liter (mg/l) and ranged from 0.10 to 2.00 mg/l. The measured chlorine residuals did not follow values predicted from plant flow and chlorine application rate.

4. Total available chlorine residuals at Plant 1 had a mean value of 0.29 mg/l and ranged from less than 0.10 to 0.75 mg/l.

5. Total coliform densities at the surface above the outfalls from the two Bremerton treatment plants showed no direct relationship with chlorine residuals measured in the plant.

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6. Background total coliform densities in Sinclair Inlet and Port Washington Narrows were generally less than 10/100 ml at mid-channel and increased toward shore. Nearshore samples were still low (less than 200/100 ml) except above sewage outfalls. A total coliform count of 510,000/100 ml was measured above the Port Orchard outfall.

7. Total coliform densities of 70,000/100 ml were found in a dye-marked waste plume 500 to 600 yards away from the outfall of Bremerton Plant 2. Levels between 70,000 and 97,000/100 ml were found simultaneously at several points between the surface boil and the 600-yard mark of the plume.

8. Total coliform densities as high as 1500/100 ml were found on an ebb tide 750 yards from the outfall of Bremerton Plant 1. On a flood tide, counts of 400 to 700/100 ml were found up to 700 yards from the outfall in an area reportedly used for clam digging.

9. Sewage plumes produced by both Bremerton outfalls, as defined by bacteriological analyses and dye tracers, had sharp boundaries. Total coliform densities found inside such boundaries were up to 140 times greater than those found outside the boundary.

10. The receiving waters immediately surrounding both Bremerton outfalls and the Port Orchard outfall were frequently discolored by the sewage discharges and gulls were observed

on numerous occasions feeding on particulate matter in the effluent.

11. Waste discharges from the Puget Sound Naval Shipyard are responsible for wide fluctuations in flow at Bremerton Plant 2. These wastes intermittently produce low pH and hazardous concentrations of oil and solvents in the plant.

Conclusions

1. Adequate disinfection of the effluents from the two Bremerton treatment plants cannot be obtained consistently with existing treatment and chlorination practices. A review of the literature indicates that inconsistent disinfection is typical for primary-treated sewage.

2. The wastes from the two Bremerton treatment plants intermittently produce total coliform densities in Sinclair Inlet and Port Washington Narrows exceeding the levels recommended in the approved water quality standards. Analyses of total coliform densities found over each of the two outfalls indicate the probability of counts exceeding 1000/100 ml is 35 to 40 percent at Plant 1 and 65 to 70 percent at Plant 2. The probability of counts exceeding 2400/100 ml is 20 to 25 percent at Plant 1 and 55 to 60 percent at Plant 2.

3. Effluents from primary sewage treatment plants are responsible for the preponderance of total coliform bacteria found in Sinclair Inlet and Washington Narrows.

4. A review of the literature indicates that data on the effectiveness of one system utilizing primary treatment, chlorination, and marine disposal cannot readily be applied to other similar systems.

5. Large numbers of samples collected over a short time interval (hours or days as opposed to weeks or months) are required to adequately define the transient effects of wastes discharged into tidal waters through outfall systems.

Recommendations

1. The City of Bremerton is presently conducting an engineering study of their existing waste treatment and disposal system. For the Charleston Treatment Plant (Plant 2) the study should include plans for the installation of secondary treatment. As interim measures the City should:

   a. Extend the outfall to deeper water and install a diffuser.

   b. Cease the direct discharge of untreated digester supernatant.

   c. Initiate a program to optimize disinfection at the existing facilities. This program should determine the optimum chlorine dosage rates and residuals based upon plant tests relating flow, chlorine feed rate, chlorine demand, chlorine residual, and bacteriological levels in the effluent. Sampling should be scheduled to record hourly and daily variations.

2. For the Manette Plant (Plant 1) the study should include plans f the installation of secondary treatment, unless the City can demonstrate to the regulatory agencies (through detailed engineering and water quality studies) the adequacy of a properly operated primary treatment plant. In any case, to improve the performance of the existing plant the City should:

   a. Install a suitable chlorine contact chamber.

   b. Install a diffuser on the existing outfall.

   c. Cease the direct discharge of untreated digester supernatant.

   d. Initiate a program to optimize disinfection at the existing facilities. This program should determine the optimum chlorine dosage rates and residuals based upon plant tests relating flow, chlorine feed rate, chlorine demand, chlorine residual, and bacteriological levels in the effluent. Sampling should be scheduled to record hourly and daily variations.

3. The United States Navy, Puget Sound Naval Shipyard, should initiate action to:

   a. Modify the operation of their sewage collection system so as to minimize hydraulic surges at Bremerton Plant 2.

   b. Provide adequate pretreatment to insure that strong acid or alkaline wastes, oils, solvents, and other exotic wastes are not discharged directly to the Bremerton municipal treatment facilities.

STUDY AREA

General Description

Sinclair Inlet and the Port Washington Narrows are located in central Puget Sound, 15 miles west of Seattle, Washington (Figure 1). Sinclair Inlet is an embayment approximately five miles long and three quarters of a mile wide. Water depths at mean low water vary from 20 to 25 feet at the western end to over 50 feet at the eastern end. Sinclair Inlet is connected to the main part of Puget Sound by Port Orchard and Rich Passage.

Port Washington Narrows is the four-mile-long channel that connects Sinclair Inlet and Dyes Inlet, another enclosed embayment. The Narrows averages about one-quarter of a mile in width and has a water depth at mean lower low water generally less than 25 feet.

Figure 2 is a more detailed map of the study area. The region is dominated by the City of Bremerton, which is situated along the northern edge of Sinclair Inlet and on both sides of Port Washington Narrows. This city, with a population of 40,000 is economically oriented around the Puget Sound Naval Shipyard which employs several thousand people. Smaller population centers are Gorst, at the western end of Sinclair Inlet, and the Port Orchard-Annapolis area along the southern shore ot the Inlet. Total population for the study area is over 50,000.

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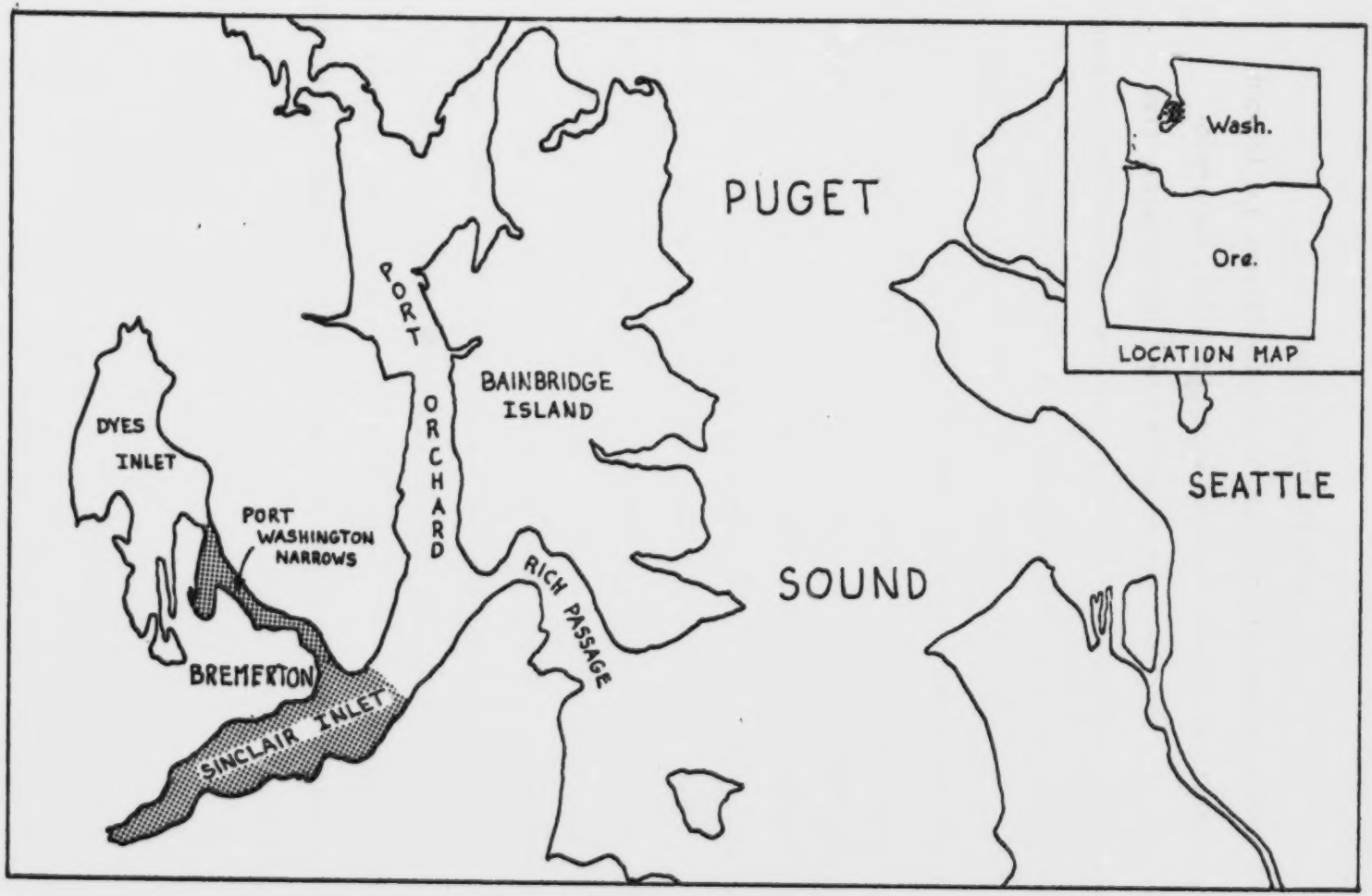

FIGURE 1. Study Area

Waste Sources

The major waste sources in the area are the outfalls from the two City of Bremerton waste treatment plants and the two outfalls in the Port Orchard area. The locations of these outfalls are shown on Figure 2. Table 1 lists general characteristics of these sources.

TABLE 1

TREATMENT PLANTS IN STUDY AREA GENERAL CHARACTERISTICS

Source	Volume, mgd	Population Served	Type of Treatment System
Bremerton Plant 1 (Manette)	2.9	25,000	Primary + chlorination
Bremerton Plant 2 (Charleston)	2.5	15,000	Primary + chlorination
Port Orchard	0.5	4,000	Primary + chlorination
Annapolis Sewer District	0.3	3,000	Primary + chlorination

The Puget Sound Naval Shipyard, although a major waste producer, discharges very little directly to Sinclair Inlet. The domestic wastes from the shore facilities in the shipyard are collected and treated in the Bremerton treatment plants, primarily Plant 2. Lesser amounts of domestic wastes from the active ships in the yard are discharged directly to the Inlet. Industrial wastes are discharged to the Bremerton treatment system after some pretreatment or are handled separately.

Water Uses and Quality Standards

The waters of Sinclair Inlet and Port Washington Narrows are subject to a variety of uses. The State of Washington Water Quality Standards for Interstate and Coastal Waters designates these waters as Class A (with special conditions for bacteria). Uses associated with this class of marine waters include commerce and navigation; fish and shellfish reproduction and harvesting; wildlife habitat; and general recreation and aesthetic enjoyment (picnicking, swimming, fishing, skiing, and boating). The recreational uses are dominant in the study area.

The quality standards associated with Class A waters are high. Of particular interest in this study is the standard for total coliform bacteria. The State of Washington has established special conditions for Sinclair Inlet and part of Port Washington Narrows which read:

> Special Conditions
>
> Sinclair Inlet and Port Washington Narrows West of Longitude 122° 37' W and south of Latitude 47° 35' 20" N.
>
> Total Coliform Organisms-Shall not exceed median values of 1000 with less than 20% of samples exceeding 2400 when associated with any fecal source.

The special condition area is shown in Figure 2. The remainder of Port Washington Narrows and Dyes Inlet has a regular Class A total coliform standard for marine waters:

> Total Coliform Organisms - shall not exceed median values of 70 with less than 10% of samples exceeding 230 when associated with any fecal source.

Current and Tidal Patterns

Current patterns in the study area, as in Puget Sound generally, are complex and variable. The size and shape of Sinclair Inlet indicates that strong, well-defined currents would be unlikely. In fact, the direction and magnitude of currents is so weak and variable that accurate predictions are not possible for Sinclair Inlet. There are probably significant time intervals, such as over slack-tide periods, when there is little or no water movement. This is particularly true adjacent to the shore and in the upper reaches of the inlet. Wastes discharged during these stagnant periods would concentrate in the immediate vicinity of the outfall. An evaluation of water quality during these "pooling" periods is an important aspect of this study.

The currents in Port Washington Narrows present a very different picture. Predicted velocities range from 1.0 to 1.7 knots at the southern end to over 2.0 knots at the northern end. The water is very turbulent. Any slack periods which occur exist for a very short time and affect only small portions of the water mass. The effects of this current pattern on wastes from Bremerton

Treatment Plant No. 1 are discussed in the Results and the Discussion sections of this report.

Water Quality

Water quality data for Sinclair Inlet and Port Washington Narrows are limited. The only known data are those collected by the surveillance program of the WPCC. There are three monitoring stations in the study area. Two are located in Sinclair Inlet near the center of the bay and one is in Port Washington Narrows. Prior to this survey, these stations were sampled a total of six times in two years. These data, though limited, show total coliform levels generally less than 60/100 ml with a maximum of 220/100 ml. Values for other parameters also indicate water of high quality.

DESCRIPTION OF TREATMENT PLANTS

Plant Design

Bremerton Plant No. 1 (Manette) and Plant No. 2 (Charleston) are typical primary treatment plants in which the incoming waste passes through successive operations of grit removal, grinding, settling, and chlorination. The solids that are removed are further treated in an anaerobic digestor. Table 2 summarizes pertinent information for the two plants.

TABLE 2

DESIGN FEATURES OF BREMERTON TREATMENT PLANTS

Item	Plant No. 1	Plant No. 2
Size of incoming sewers	8" & 20" pressure	15" gravity 20" pressure
Settling basins		
Number	3	4
Total Surface Area	4,560 sq. ft.	5,760 sq. ft.
Volume	238,762 gallons	301,590 gallons
Design Flow	2.86 mgd	3.62 mgd
Design Detention Time	2.0 hrs.	2.0 hrs.
Chlorination system		
Pts. of application	Influent & Effluent	Influent & Effluent
Contact time	Negligible	20 min. @ design flow

Operating Characteristics

Waste Inflow

Inflow patterns at the two plants vary widely even though their average daily dry-weather flows are approximately equal (2.8 mgd). At Plant 1 the flow is characterized by many evenly

spaced, short term variations due to pump station operation. The instantaneous flow rate varies approximately 3.0 million gallons per day (mgd) with peak rates occurring every 10 to 12 minutes.

At Plant 2, short term fluctuations are also present. The most important characteristic of the inflow pattern, however, is a series of waste surges each lasting 20 to 30 minutes. These surges occur every 1½ to 2 hours and result from the pumping of the master pump station for the Naval Shipyard. During these periods the flow rate may reach 4.8 mgd which is almost twice the average flow.

The sewage collection system feeding both plants contains numerous pumping stations. The portion of the system connected to Plant 1 contains three primary pump stations which in turn are connected to seven secondary stations. For Plant 2 there are a total of 16 pump stations, nine of which are located in the Naval Shipyard. Detention times for the waste in the collection system is estimated to be 3 to 4 hours.

Digestor Operation

The solids removed by settling in the primary clarifiers are pumped into the digestors, usually once a day. The volume of solids pumped averages 2,200 gallons per day (gpd) but varies from 1,500 to 3,000 gpd. As this material is pumped into the digestor, a corresponding amount of liquid is displaced. This overflow is usually bypassed directly into the outfall without chlorination. The physical capability exists for recycling the

supernatant through the plant, but to avoid odor problems this practice is not followed.

Chlorination Practices

Both plants use pre- and post-chlorination. Generally, the feed rates are 100 to 125 pounds per day (lb/day) of liquid chlorine for pre-chlorination and 125 to 150 lb/day for post-chlorination. Equipment is available at both plants to add the chlorine at a rate proportional to the flow. At Plant 2, however, the proportional chlorine feeder has a history of malfunctions and the chlorine is usually added at a constant rate. This was the case during this survey. The chlorine feeder is operable at Plant 1.

The major difference between the disinfection procedures at the two plants is the contact time provided following addition of the chlorine. As indicated in Table 2, Plant 1 provides negligible contact time. Chlorine is added just prior to discharge of the waste into the outfall. The total contact time provided during flow through the outfall line is approximately 2 to 3 minutes.

The facilities at Plant 2 include a flash-mixing basin and a contact chamber sized to provide a 20-minute detention time at design flows. At the peak flows of 4.8 mgd the detention time is about 17 minutes; it approaches 40 to 45 minutes during the low flow periods of the day. In addition, the outfall line provides up to six minutes of contact.

Treatment Efficiencies

Little routine information is available on the treatment effeciencies of the two plants. Because of limited staff and facilities, biochemical oxygen demand (BOD) tests were not conducted. Chlorine residuals are noted 3 or 4 times daily but only the average of the observations is recorded. Bacteriological data on plant operations are not collected.

The only previous survey of the two Bremerton treatment plants was conducted during June, 1969, by the WPCC. Table 3 shows the results of the evaluation. The extremely low pH at Plant 2 are thought to be the result of industrial activity at the Naval Shipyard. Total coliform levels in the effluent were also low at Plant 2 during the WPCC survey. This may be partially due to the toxic effects of the low pH values. In contrast, four out of five effluent samples from Plant 1 had total coliform concentrations greater than 1,000,000/100ml.

Outfall Characteristics

The outfall line for Plant 1 consists of 400 feet of pipe, 20 inches in diameter, extending about 200 feet into Port Washington Narrows. Wastes are discharged directly out the end of the pipe as no diffusers were built into the line. Water depths over the end of the pipe are approximately 15 feet during low tide and 25 to 30 feet at high tide.

Table 3

TREATMENT PLANT EVALUATIONS, JUNE, 1969

Item	Plant 1	Plant 2
pH		
Influent (mean & range)	7.3, 6.8-7.9	5.0, 1.9-7.1
Effluent (mean & range)	6.9, 6.4-7.2	5.3, 2.4-7.0
5-day BOD, mg/l		
Influent	160	66
Effluent	100	41
% Reduction	38	38
Suspended Solids, mg/l		
Influent	220	300
Effluent	90	140
% Reduction	59	53

Effluent Total Coliform[a/] Densities (TCD) with Associated Chlorine Residuals (CR)

TCD (100 ml)	CR (mg/l)	TCD (100 ml)	CR (mg/l)
20	0.3	1500	0.4
1,000,000	0.05	500	0
3,000,000	0	3400	0
1,000,000	0.05	20	0
2,500,000	0	20	0

a/ Tests conducted using membrane filter (MF) technique, samples taken over an 8-to-10-hour period.

The Plant 2 outfall has a diameter of 24 inches and is 700 feet in length. At high tide the line extends underwater approximately 150 feet into Sinclair Inlet and has about 15 feet of water over the end. At low tide water depths at the end are 5 to 8 feet. During extremely low tides, the end of the pipe is just under the surface. As with Plant 1, there is no diffuser section in the pipe.

The combination of location, depth, and lack of diffusers for these outfalls provides for a minimum dilution. The minimum surface dilution over the outfall at Plant 1 is calculated (2) to be about 6:1 for low tide periods and 12-15:1 at high tides. These theoretical dilutions are based on a flow of 2.8 mgd which approximates the average daily waste discharge. Using the same flow for the Plant 2 outfall, the maximum dilution which might be expected during high tides is about 4:1. At low tide the theoretical dilution is less than 2:1.

SAMPLING PROGRAM

Reconnaisance Survey

A reconnaisance survey of Sinclair Inlet and Port Washington Narrows was conducted on August 25, 1969. The purpose of the reconnaisance was to obtain information to formulate a rational sampling program for the main survey. The information sought included: the location of sewage treatment plant outfalls, the gross current patterns affecting the outfalls, methods of identifying the sewage field in the receiving waters, the vertical distribution of bacteria within the sewage field, and the effect of sample handling methods on results. The conclusions of the reconnaisance are:

1. Sewage plumes produced by the Bremerton outfalls are difficult to identify at water level. Therefore, dye was added to the effluent to assure that the plume could be located and sampled.

2. Coliform bacteria densities were greatest at or near the water surface. Sampling during the main surveys was confined to the surface layer of water (0-1 foot depth). This approach allowed more samples to be collected during a short time period and resulted in a more precise definition of lateral and longitudinal distribution of bacteria.

3. A minimum sample holding time of three hours was anticipated if analytical work were to be done at the WPCC laboratory in Olympia, Washington. Coliform densities were significantly reduced in iced

samples held three hours at 0^{o} C. This problem was minimized by using a mobile laboratory to conduct the analyses as soon as possible after sample collection (two hours maximum sample holding time).

The main survey plan developed from this reconnaissance was for a three-day sampling effort. One day was for a background bacteriological survey and one day each was allocated for intensive inplant and outfall sampling at the two treatment plants. The study plans for each of these surveys are discussed in the following sections.

Background Bacteriological Survey

Ideally, a background level bacteriological survey in a tidal embayment includes collection of samples from many points in the study area during all stages of the tide. The resource requirements for such a sampling program were not available for this survey; therefore, samples were collected from several points at high and low slack tides. There are two primary reasons for sampling during slack tides. At slack water the sewage rising to the water surface from the outfall will accumulate (pool-up), at least for a short period, resulting in maximum concentrations of pollutants near the outfall. Sampling at successive slack water times also provides information on the distance the waste field travels during rising and falling tides.

Ten sampling lines were established in the study area. One to five sample points were selected along each line,

depending upon the channel width. For the longer cross-sections, sampling points were located as follows: 20 to 30 yards off each shore, 200 to 300 yards off each shore, and mid-channel. At the narrower sections only the nearshore and mid-channel points were sampled.

Each known sewage outfall was sampled in addition to the cross-section stations. As a control, a sampling point was established in Rich Passage approximately three miles from the junction of Sinclair Inlet and Port Washington Narrows. This area is removed from any known source of sewage.

In all, forty background sampling points were selected. This number represents a compromise between the need for a large number of samples and the need for a short sample-holding time.

On September 10, 1969, each background sampling point was visited at a high and a low slack water period. Two boats were used to collect the samples. The running time required to complete the sampling was about 45 minutes. Sample delivery and preparation extended the interval between first sample collected and last sample processed to two hours.

Plant 2 Survey

Receiving Water Sampling

The receiving water sampling program had three elements; (1) hourly paired samples in the surface boil over the outfall,

(2) cross-sectional sampling of the sewage pooled at a high and a low slack water period, and (3) cross-sectional sampling of the sewage plume on a flood and an ebb tide. The sample schedule was designed to answer the following questions:

1. What is the range of total coliform densities in the surface boil?
2. What is the size of the sewage field formed during slack water?
3. What is the distribution of total coliforms in the pooled sewage field?
4. What is the form of the sewage plume produced by the outfall during an ebb and a flood tide?
5. What is the distribution of total coliforms in the sewage plume during ebb and flood tides?

Sampling at Plant 2 began at low slack water on September 9, 1969. Rhodamine B dye was added to the sewage effluent just prior to low slack tide to provide visible evidence of the sewage field. The pooled sewage defined by the dye was sampled 15 minutes after the first appearance of the dye in the surface boil.

As the tide rose, current drogues and the dye outlined the waste plume. Three sampling lines 150 yards apart were established on each side of the outfall. Sampling points were established along each line section at 30-yard intervals, beginning at the shoreline and extending 150 yards offshore to the outside of the dye mass. Selection of sampling points was based on location

of the dye mass and current. Samples were also taken upstream from the plume as a control. The plume sampling was repeated three times during the flood tide.

A second dye release was made at high slack water. Cross-sectional sampling of the pooled sewage and the ebb plume was similar to that for the low slack pool and the flood plume. Sampling of the ebb plume, however, was limited by darkness to one sample run.

In-Plant Sampling

In-plant sampling at Plant 2 was conducted concurrently with the work in the receiving water. The in-plant sampling provided information on the hydraulic, chemical, physical, and bacteriological characteristics of the effluent.

Effluent samples were collected at the end of the chlorine contact chamber every half hour between 8:00 am and 3:30 pm. The following field analyses were performed on each sample: temperature, pH, conductivity, and total available chlorine. Six effluent samples were also analyzed for total coliform density.

A flow-proportioned composite was made from the half-hourly effluent samples. This composite was analyzed for BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), total solids, total non-volatile solids, total suspended solids, and non-volatile suspended solids.

Five influent samples were collected and analyzed for total coliform concentration as an index of sewage freshness.

Sewage flow rates and chlorine dosage were also documented.

Plant 1 Survey

The sampling program for Plant 1 was essentially the same as the Plant 2 program. Tracer dye was used more frequently at Plant 1. Either Rhodamine or Fluorescein dye was added to the effluent prior to the hourly sampling. The additional dye was necessary because the effluent did not produce an obvious waste field under most conditions.

Analytical Methods

All chemical and bacteriological analyses were performed in accordance with the 12th Edition, Standard Methods for the Examination of Water and Wastewater (3). The following specific analytical methods were used where equivalent alternative methods are available:

Total coliforms - membrane filter technique
Suspended solids - Gooch crucible with glass pad.
Chlorine residual - orthotolidine with color comparator

Bacteriological analyses were started as soon as possible after sample collection to minimize possible bacterial reductions during sample holding. In most cases, the samples were processed and incubation started within two hours after the samples were taken.

RESULTS

Background Survey

The total coliform bacterial levels found during the low slack background survey were generally low, as shown in Figure 3. Of the 40 samples analyzed, 28 showed less than 20 total coliforms per 100 milliliters (TC/100 ml) and seven had counts over 100 TC/100 ml. These higher counts were associated with the waste outfalls from the Port Orchard and Bremerton No. 2 treatment plants. The value shown for the Plant 1 outfall indicates a total coliform count of less than ten. Since the effluent was not dyed during the background survey and the waste plume at Plant 1 could not be identified, it is likely that this value reflects the background level in the area rather than the actual waste strength. The waste plume at the other two outfalls was obvious and the samples were taken directly in the boil.

Figure 4 shows the levels found during the high water slack. The counts were generally higher than those found during the low slack run. Levels in mid-bay approached the low counts found at the control station and consistently increased towards the shore. As in the previous case, the highest levels were found in the vicinity of the two outfalls in Sinclair Inlet.

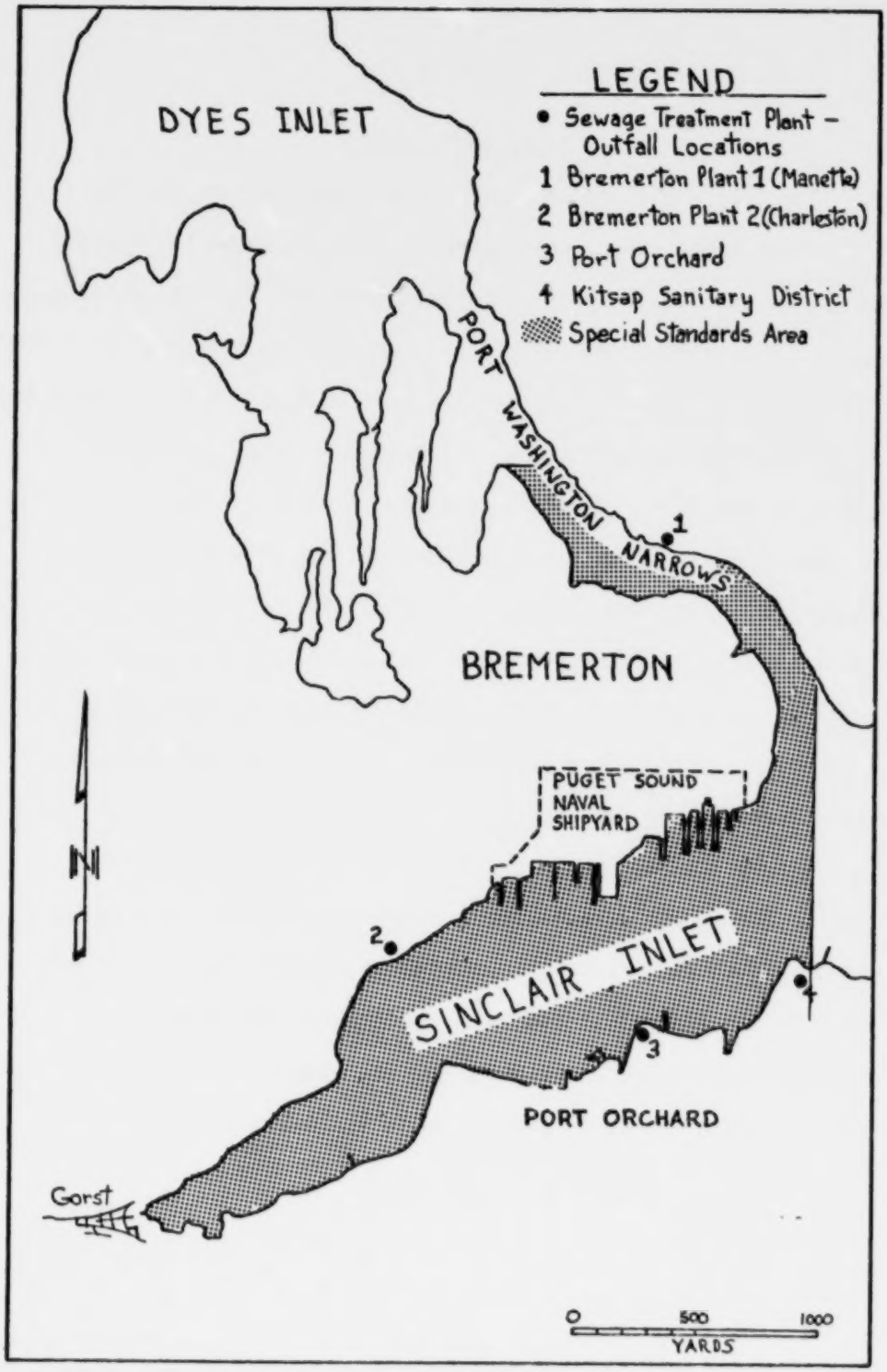

FIGURE 2. Detailed Map of Sinclair Inlet-Port Washington Narrows

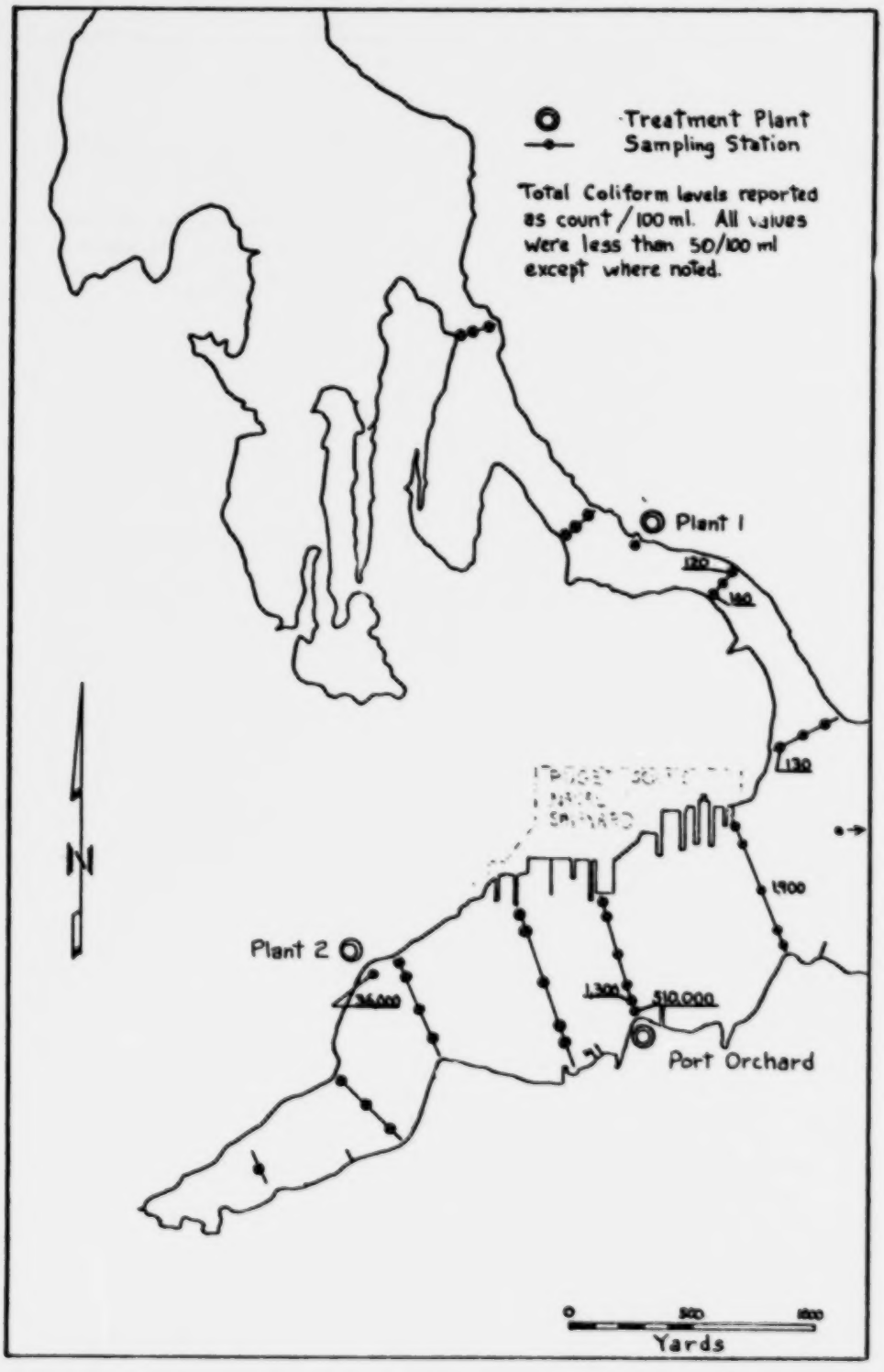

FIGURE 3. Background Total Coliform Levels - Low Slack Tide - Sept. 10, 1969

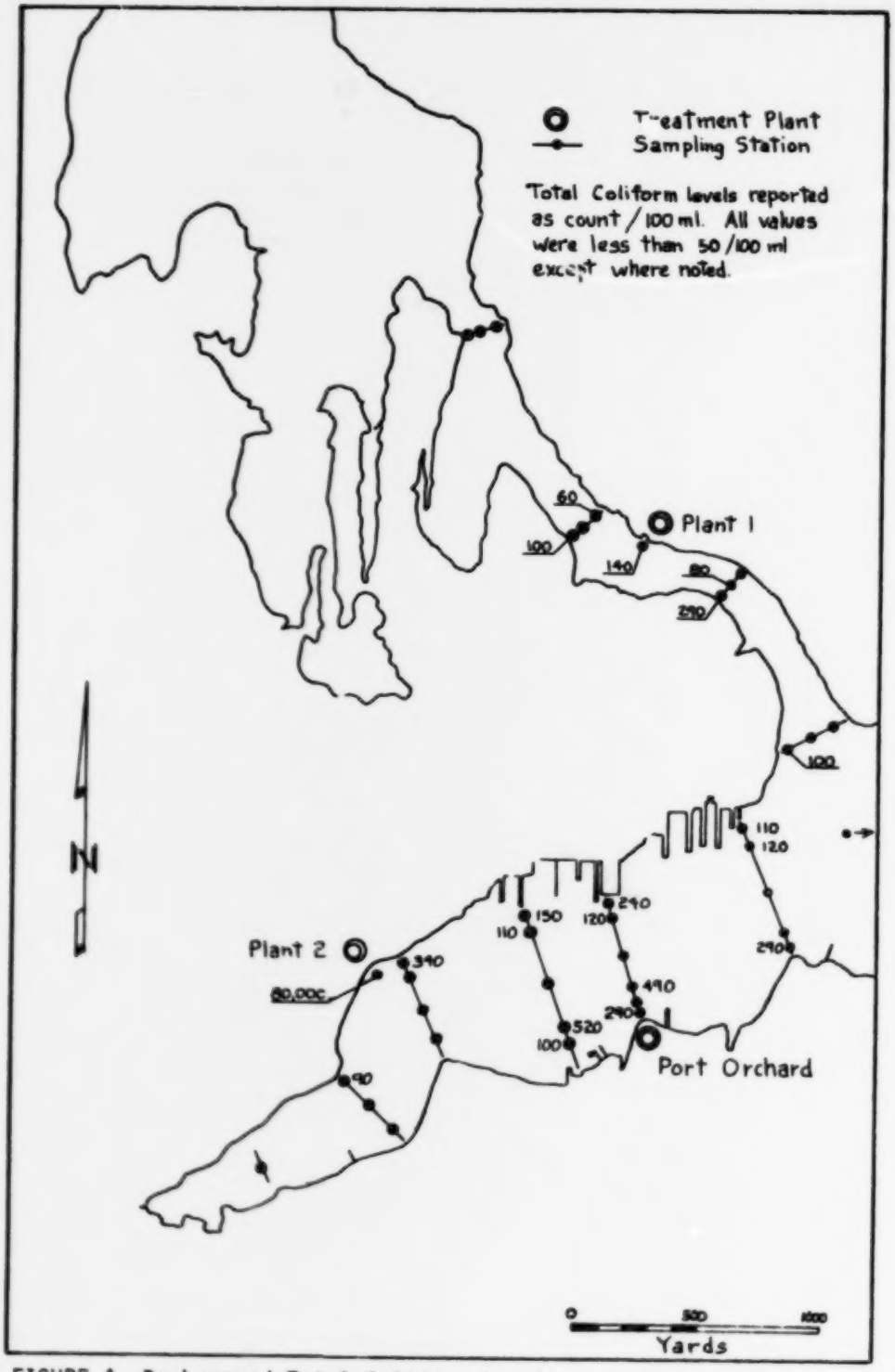

FIGURE 4. Background Total Coliform Levels - High Slack Tide - Sept. 10, 1969

Plant 2 Survey

In-plant Data

The in-plant data for Plant 2 are shown in Tables 4 and 5, which also contain comparable data for Plant 1. The values for Plant 2, with the exception of conductivity and total solids, are typical of effluents from primary treatment plants. The higher conductivity and total solids are due to salt water infiltration in the Naval Shipyard.

The coliform and chlorine residual data presented in Table 5 are shown in detail to indicate the variability found in these parameters. The significance of these variations will be evaluated in the discussion section of the report.

Late in the afternoon of September 10, 1969, considerable quantities of a volatile organic solvent were observed in the plant influent. This material was being introduced into the plant by the force main originating in the Naval Shipyard. Concentrations were such that all visible water surfaces were covered and the odor was quite strong near the plant.

TABLE 4

CHEMICAL CHARACTERISTICS OF BREMERTON
TREATMENT PLANT EFFLUENTS DURING
THE STUDY PERIOD

Item[a/]		Plant 1 (9/11/69)	Plant 2 (9/9/69)
1.	pH		
	Mean	6.9	6.9
	Range	6.1-7.3	6.8-7.1
2.	Conductivity, µmhos/cm		
	Mean	1207	5000
	Range	670-2500	3200-5700
3.	Biochemical Oxygen Demand, 5-day 20° C, mg/l	120	140
4.	Total solids, mg/l	800	3180
5.	Total volatile solids, mg/l	230	620
6.	Total suspended solids, mg/l	100	150

a/ Items 1 & 2 determined at ½-hour intervals. Items 3-6 determined on composite sample.

TABLE 5

EFFLUENT TOTAL COLIFORM LEVELS AND
CHLORINE RESIDUALS DURING THE STUDY PERIOD

	Plant No. 1 (9/11/69)		Plant No. 2 (9/9/69)	
Time	Total Chlorine Residual, mg/l	Total Coliform Count /100 ml	Total Chlorine Residual, mg/l	Total Coliform Count /100 ml
0830	0.35		2.00	
0900	0.35		1.0	
0930	0.35	3,600	0.75	
1000	0.50		0.75	290
1030	0.35		1.40	
1100	0.50		0.35	500
1130	0.35	7,800,000	0.50	600
1200	0.10			
1230	0.10		0.20	3,300
1245	0.10	99,000		
1300	0.10		0.75	
1330	0.10		2.00	
1400	0.20		0.50	
1430	0.35	3,100,000	0.75	
1500	0.35		2.0	20
1530	0.75		0.10	
1600	0.10			
1715			0.20	70,000
1830	0.15			
Mean	1.29		0.88	

Receiving Water Data

Total coliform densities in the surface boil are shown in Table 6. The geometric mean coliform concentration in the Plant 2 outfall was 4,500 TC/100 ml and the median was 2,300 TC/100 ml. Forty-eight percent of the samples had counts higher than 2,400 TC/100 ml. The data also show close agreement between the counts for the paired samples taken at any one time. The surface boil at Plant 2 is very easy to locate visually, and the reproducibility between paired samples further verifies that the values shown are representative of the coliform concentration above the outfall.

The results of the slack water sampling at Plant 2 are shown on Figure 5. Total coliform levels at low slack tide were very high and have an interesting distribution. The higher counts appear at the outer edges of the sampling pattern and the count in the boil is considerably lower. The most probable explanation of this distribution is that at some time prior to the sampling run the wastes discharged had considerably higher coliform levels than those at the time of sampling. The result is a band of high coliform counts surrounding the outfall.

At high slack tide a definite pattern was not apparent. The highest count, 99,000 TC/100 ml, was found in the surface boil. The counts for the surrounding samples are generally much lower. There is some indication of a "pooling" effect on one side of the outfall with counts of 10,000 TC/100 ml and 9,800 TC/100 ml found in samples adjacent to the boil.

TABLE 6

TOTAL COLIFORM COUNTS IN SURFACE BOILS

BREMERTON PLANT 1		BREMERTON PLANT 2	
Time	Total Coliforms/100ml	Time	Total Coliforms/100ml
1000	360	1027	2,300
1000	290		
1000	470	1130	150
		1130	230
1052	2,400		
1052	29,000	1154	620
1052	26,000	1154	620
1200	10	1325	610
1200	20	1325	630
1200	40		
		1340	160
1242	4,000	1340	130
1242	1,600		
1249	160	1455	180
		1455	130
1403	4,800		
1403	1,200	1534	390
1403	2,400	1534	170
1447	3,200	1641	120,000
1447	850	1641	150,000
1605	50	1741	96,000
1605	20	1744	99,000
1605	20		
		1830	78,000
1650	70	1830	120,000
1650	1,400		
1650	100	1912	>80,000
		1913	>80,000
1830	1,300		
1831	360	1143	43,000
1831	7,100	1143	31,000
		1808	>80,000
		1808	>80,000
MEAN	3,400	MEAN	43,000
MEDIAN	660	MEDIAN	2,300
GEOMETRIC MEAN	550	GEOMETRIC MEAN	4,500
STANDARD DEVIATION	7,300	STANDARD DEVIATION	50,000

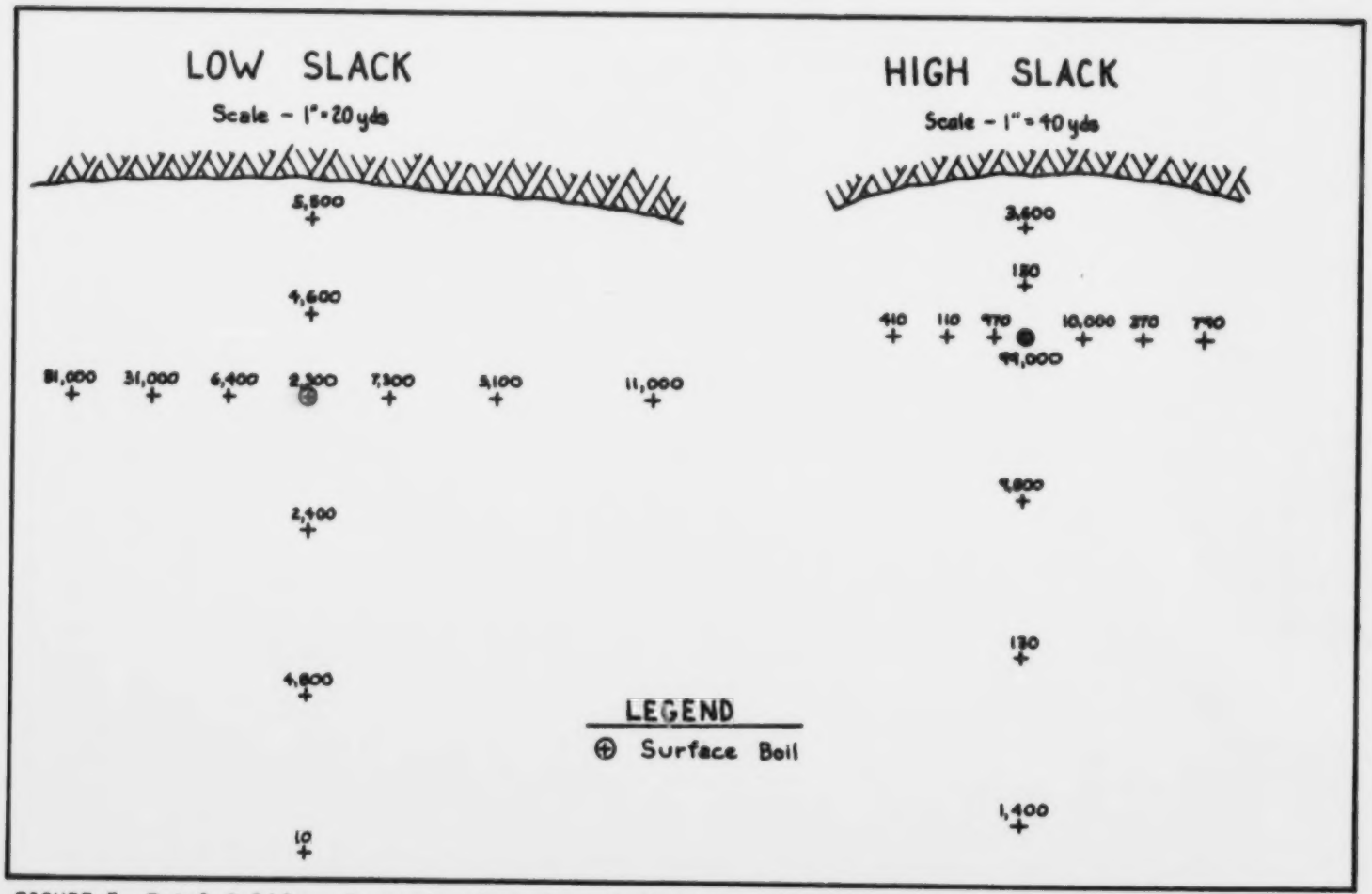

FIGURE 5. Total Coliform Concentrations Around Plant No. 2 Outfall at High and Low Slack Tide. Count/100 ml.

The results of the plume sampling conducted at Plant 2 are shown in Figures 6 and 7. On all three flood tide evaluations, shown in Figure 6, coliform concentrations were low, both in the surface boil and in the plume. The highest counts, in the 250 to 600 TC/100ml range, were found close to the shore. Beyond 50 yards offshore the counts approached background levels. Water movements in the outfall area were sluggish as indicated by both dye and current floats. During one two-hour flood tide period, current floats dropped near the outfall moved less than 100 yards.

In striking contrast to the flood tide data are the results from the ebb tide plume sampling shown in Figure 8. The effluent had a high total coliform level and a well-defined plume existed for at least 0.3 miles downstream. Of particular interest is the sharpness of the plume boundary. The count of 560 TC/100ml shown on range TV was found just outside the edge of the visible dye plume. The count of 73,000 TC/100ml represents water just inside the edge of the visible dye.

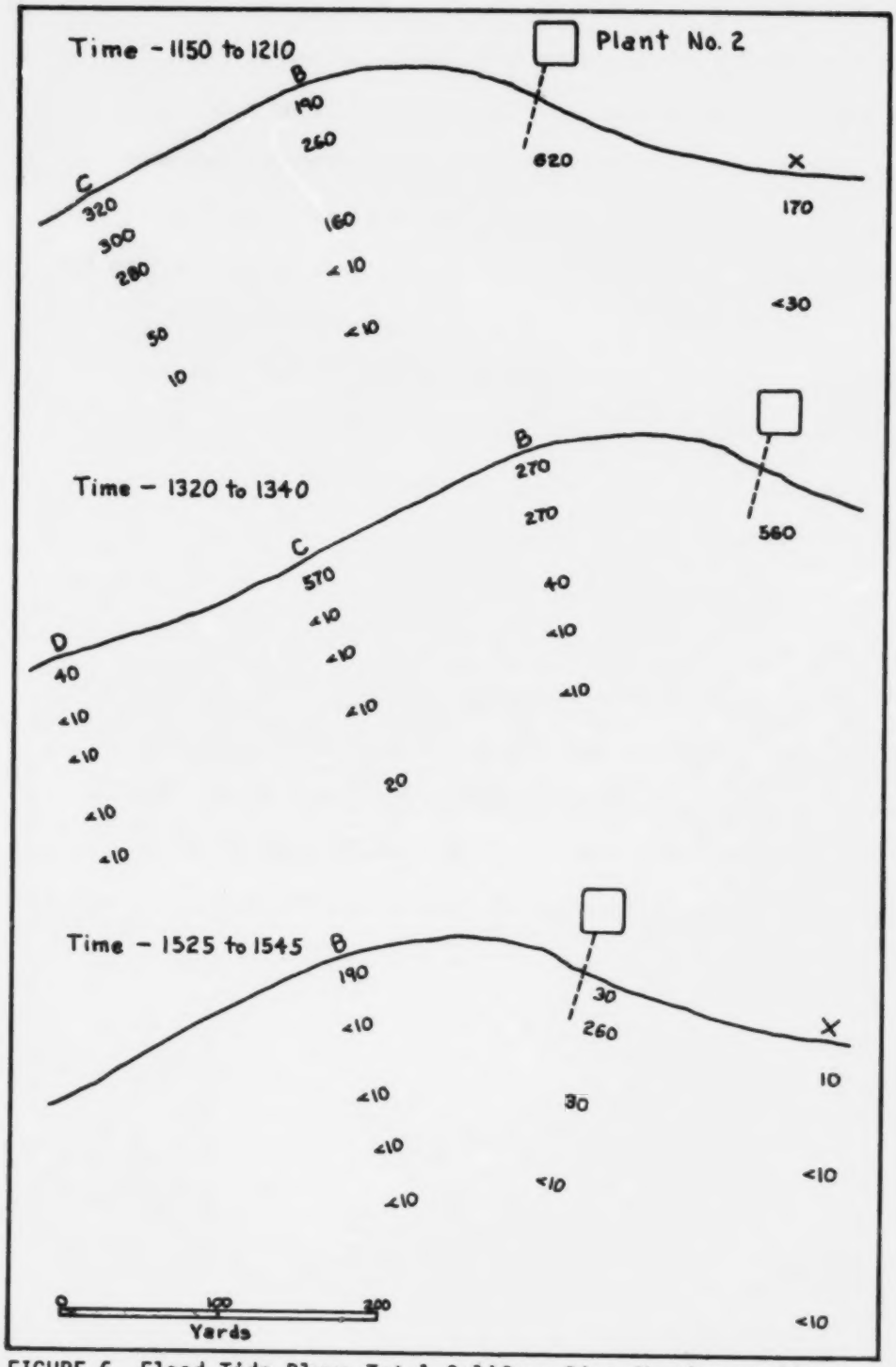

FIGURE 6. Flood Tide Plume Total Coliform Distribution at Plant No. 2 - Sept. 9, 1969. Count/100 ml.

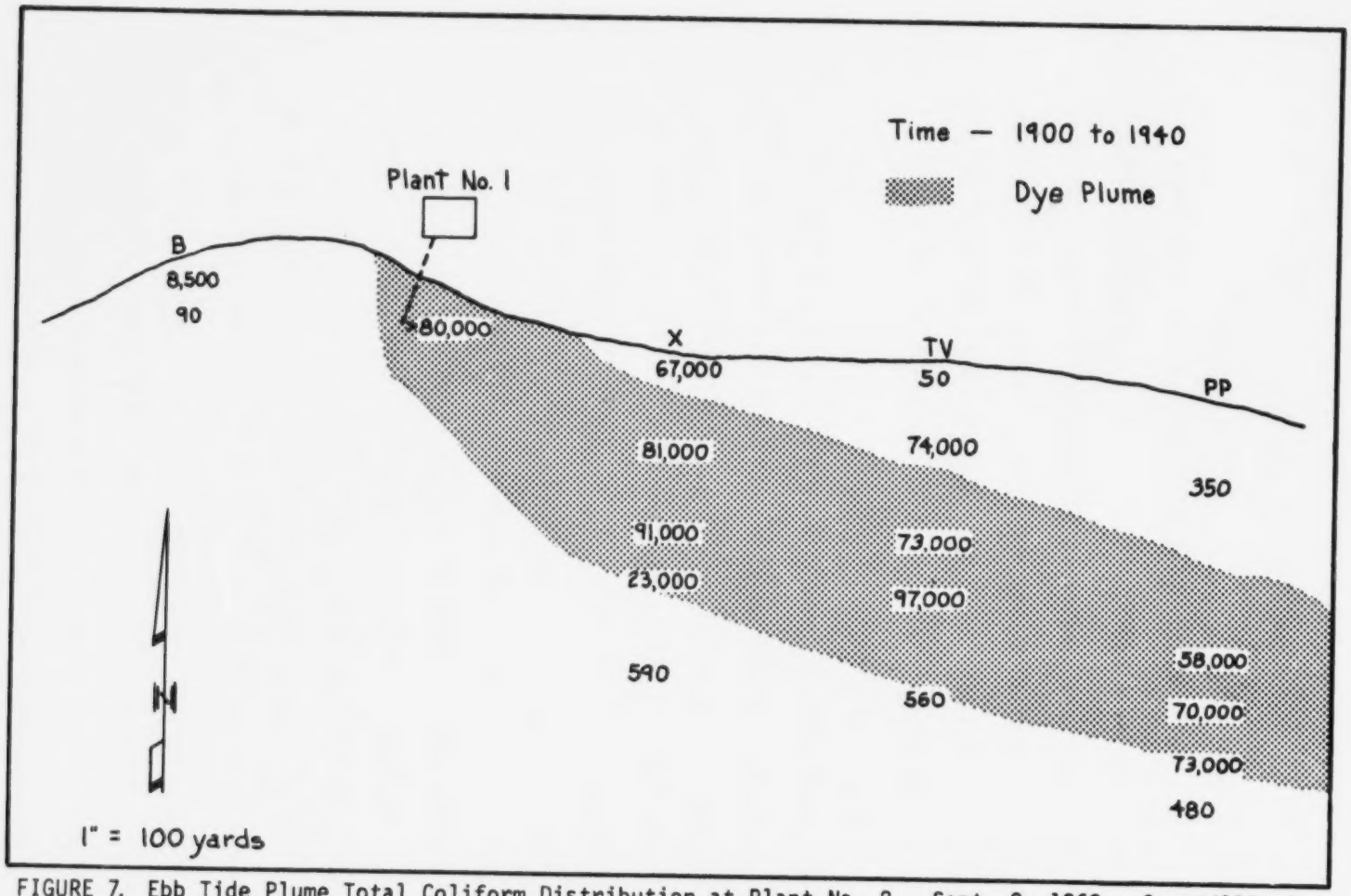

FIGURE 7. Ebb Tide Plume Total Coliform Distribution at Plant No. 2 - Sept. 9, 1969. Count/100 ml.

Plant 1 Survey

In-plant Data

The results of the in-plant sampling for Plant 1 are shown in Tables 4 and 5. The chemical and physical characteristics of the wastes are similar to those found at Plant 2 with the exception of conductivity and solids. Values for these items are lower than in Plant 2 due to a low sea water infiltration rate and a lower industrial-commercial component of the waste.

Receiving Water Data

Total coliform densities in the surface boil over the Plant 1 outfall are shown in Table 6. The geometric mean total coliform concentration was 550 TC/100ml and the median was 660 TC/100ml. Forty-six percent of the samples had coliform concentrations greater than 1000 TC/100ml. Thirty-one percent of the values were equal to or exceeded 2,400 TC/100ml. Coliform levels show a wide variance, both among sampling periods and among the replicate samples taken at any one period.

The data from the slack water sampling at Plant 1 are shown in Figure 8. A true slack water condition did not exist during the survey. At the times predicted for slack tide the water along shore and over the outfall was moving to the northwest towards Dyes Inlet. Thus, there was no actual pooling of the waste and coliform concentrations shown in Figure 8 reflect the influence of dispersion and dilution. Values are low for both tidal conditions except in the immediate vicinity of the outfall.

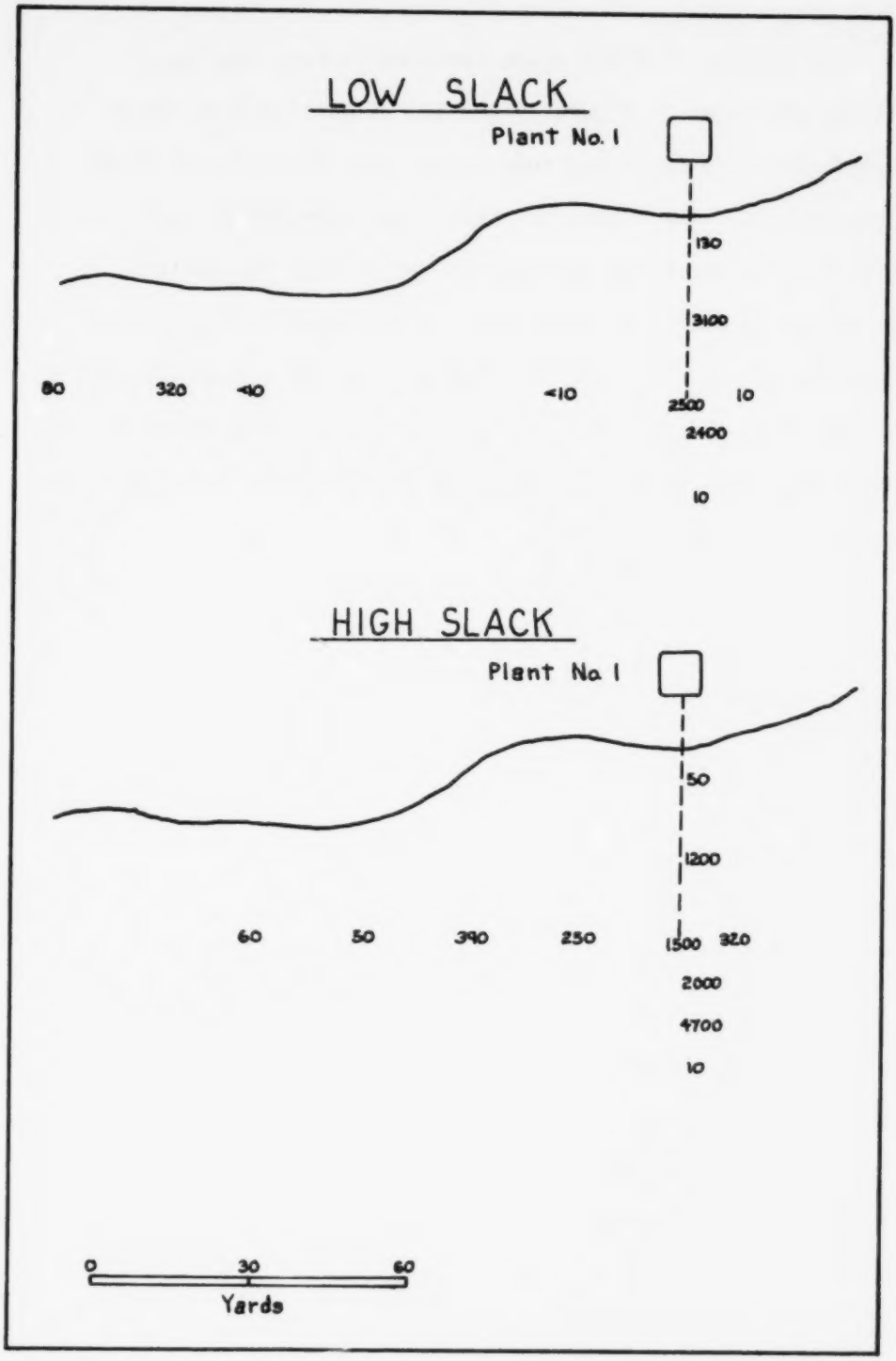

FIGURE 8. Total Coliform Concentrations Around Plant No. 1 Outfall at High and Low Slack Tide. Count/100 ml.

The results from the plume sampling in Port Washington Narrows are shown in Figures 9 and 10. Significant increases above background total coliform levels were found in all three plume studies. The plumes for both tidal conditions stayed very close to shore for at least 700 yards from the outfall. The result is that the flood tide plumes, shown in Figure 10, pass over a tide flat used for clam digging and through an area used by water skiers. The dye used to locate the plume also showed that the waste field was very patchy due to the turbulence in the receiving water.

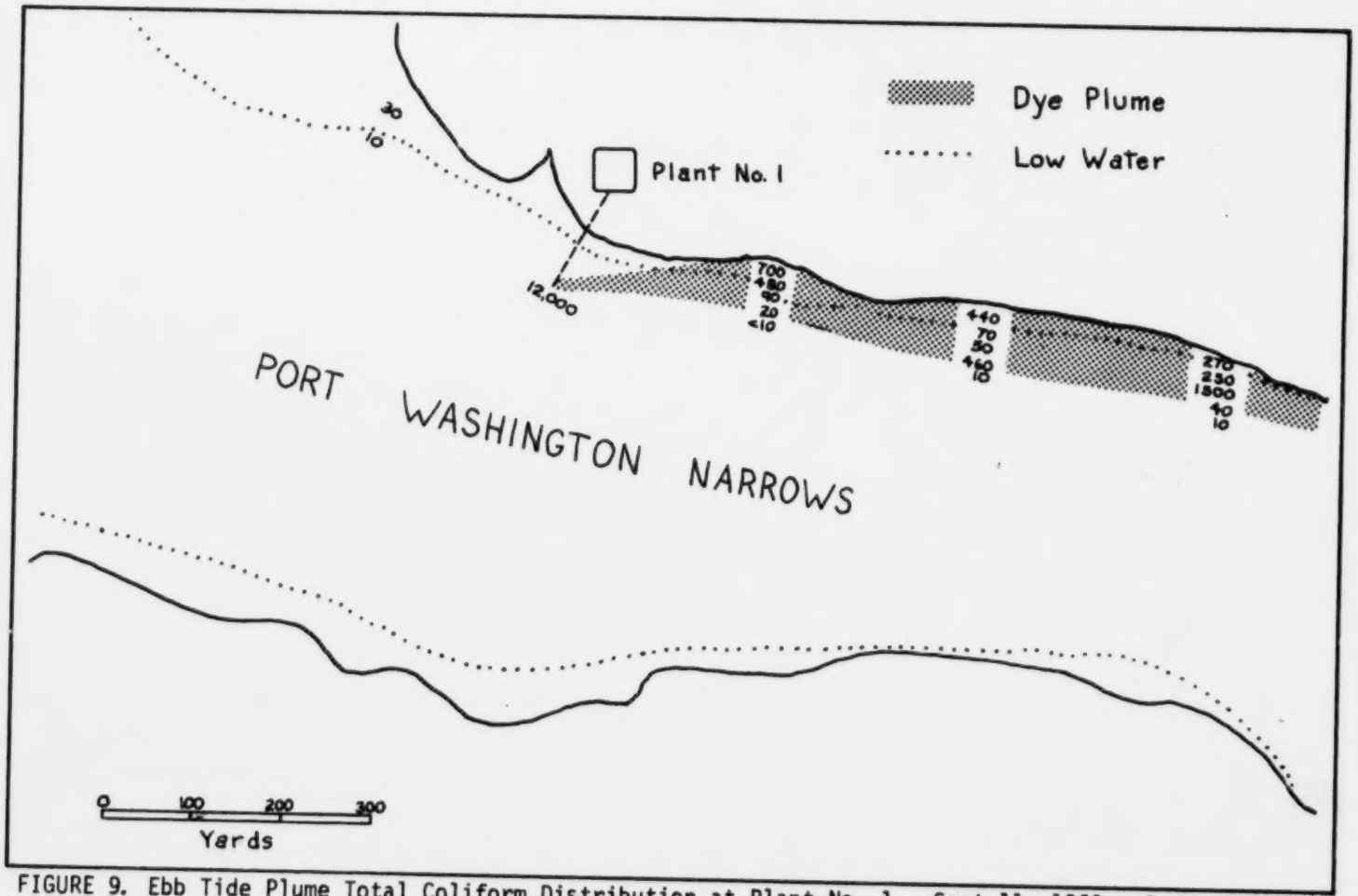

FIGURE 9. Ebb Tide Plume Total Coliform Distribution at Plant No. 1 - Sept 11, 1969. Count/100 ml.

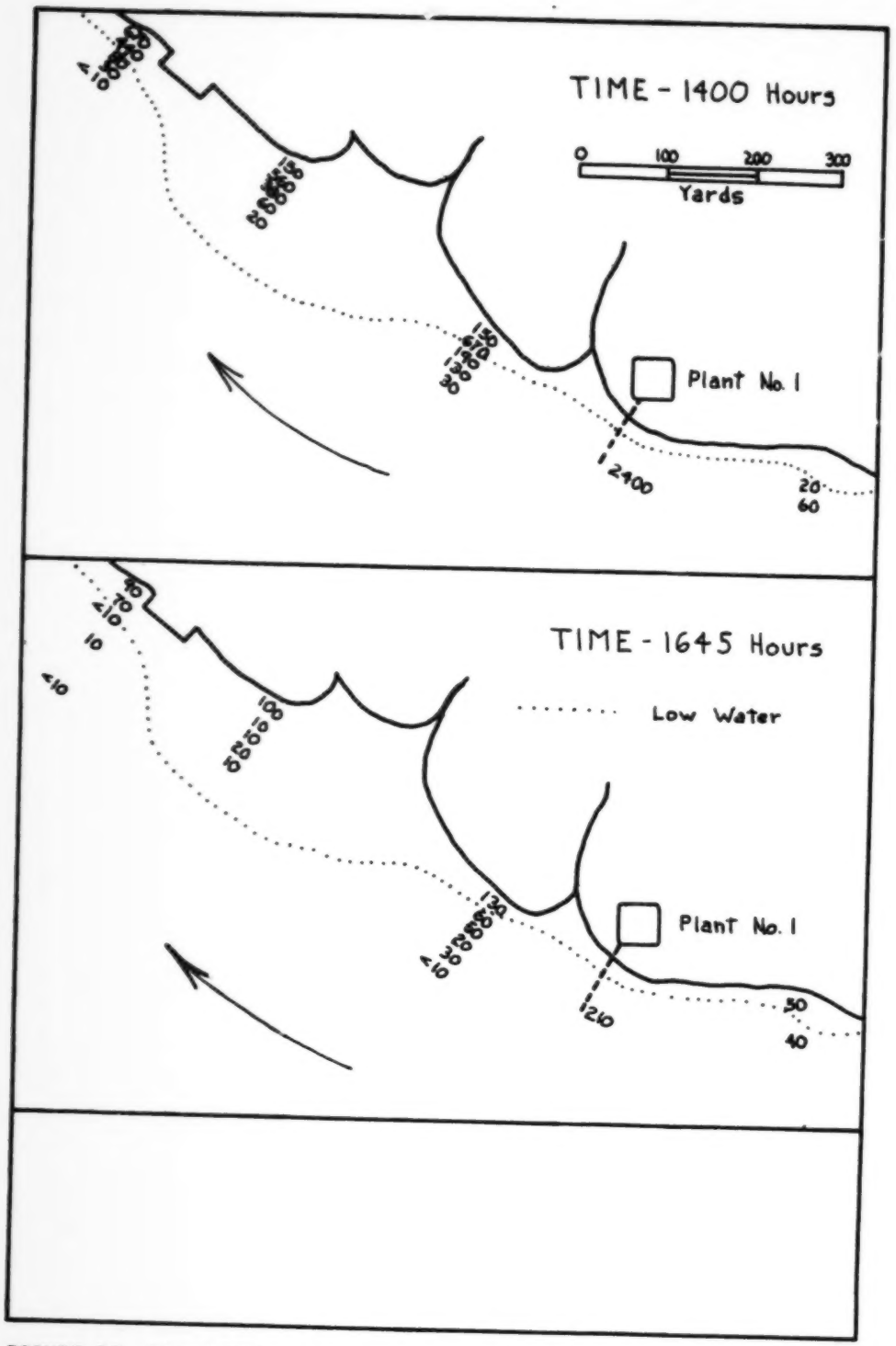

FIGURE 10. Flood Tide Plume Total Coliform Distribution at Plant No. 1 - Sept. 11, 1969. Count/100 ml.

DISCUSSION

Literature Review-Primary Effluent Chlorination

Publications dealing with the chlorination of primary treated sewage were reviewed. (Bibliography 4 through 15). The conclusions reached by these investigators regarding the effectiveness of primary effluent chlorination are:

1. Consistently high degrees of sewage disinfection are difficult to achieve, particularly in the case of primary treated sewage.

2. For a specific contact time, higher chlorine residuals are required in primary sewage than in secondary sewage to produce a given level of disinfection.

3. Chlorine residuals, and corresponding feed rates necessary to produce a desired disinfection level vary from day to day and from hour to hour because of variations in waste characteristics.

4. Two-stage chlorination is more effective for disinfection than single-stage chlorination.

5. Thorough mixing of chlorine and the sewage is essential to attain uniform coliform densities in a sewage plant effluent.

6. Increased chlorine residuals will produce decreased coliform densities, but correlations between chlorine residuals and coliform densities are not transferable from one sewage treatment plant to another.

7. Consistent disinfection is very difficult to maintain with suspended solids concentrations higher than 20 mg/l.

8. Increases in contact time reduce coliform densities more than similar increases in chlorine residual; however, increases in either factor above a certain level do not produce significant additional reductions in coliform densities.

9. The coliform test should be the primary standard for evaluating the disinfection effectiveness of chlorination in sewage effluents.

10. The effects of pH and temperature fluctuations on chlorination efficiency should be considered since alkaline wastes are more difficult to disinfect, particularly during periods of low temperature.

11. The amperometric test is the most reliable method for the measurement of chlorine residual.

The relevance of the data and observations from the Bremerton treatment plants to these conclusions is discussed below.

Relationship of Field Total Coliform Levels to Plant Operation

Variability of Chlorine Residuals

Many of the publications reviewed emphasized that chlorine demand, and therefore chlorine residuals, may vary widely over a short time period. The chlorine residual data from the Bremerton plants, shown in Table 5, show a similar lack of predictability. The target residual of 2 mg/l at Plant 2 was found only three times during the in-plant

survey and the data were characterized by large fluctuations in chlorine residual with an average dosage of 10 to 14 mg/l. The average residual was 0.90 mg/l and the values ranged from 0.10 to 2.00 mg/l. There are two probable causes for these variations. Periodic surges of waste due to the operation of pump stations produce significant changes in contact time. In addition, the differences in age and chemical composition of the incoming sewage results in wide fluctuations in chlorine demand and, therefore, chlorine residual.

At Plant 1 the chlorine residuals were more uniform although there were still significant fluctuations. The residual at Plant 1 averaged 0.29 mg/l and ranged from less than 0.10 to 0.75 mg/l. As with Plant 2 the average chlorine dosage was 10 to 14 mg/l. The lack of any significant contact time at this plant is a serious obstacle to establishing an adequate chlorination system.

Chlorine Residuals vs Effluent Coliform Levels

Data presented in the literature indicated that the disinfection efficiency for a given residual varies widely for a primary treatment system. As a result, it was very difficult to accurately predict effluent coliform concentrations in primary effluents. The data from this study support this finding (Table 5). The lack of a consistent relationship between chlorine residual and total coliform count is obvious. At Plant 1, for example, total coliform counts of 3,600/100ml, 3,100,000/100ml, and 7,800,000/100ml were associated with a chlorine residual of 0.35 mg/l. This

represents a 2,000-fold difference in bacterial concentration. Similar data were obtained at Plant 2, where counts of 3,300 TC/100ml and 70,000 TC/100ml were found in samples having a chlorine residual of 0.20 mg/l.

Examination of the coliform levels in the surface boil over the outfall also pointed out the variability in disinfection efficiency at the Bremerton plants. The variability of the data from the effluent boils, shown in Table 6, has already been discussed. In Figures 11 and 12, these values and the in-plant chlorine residuals are plotted versus time. Figure 11 shows the data from Plant 1. There is some indication of agreement between chlorine residual and coliform count in that the highest residual occurs shortly before the lowest coliform level. This pattern does not hold, however. Some of the highest coliform levels were found with relatively high chlorine residuals.

The data for Plant 2, (Figure 12) have similar inconsistencies. Coliform levels in the boil increased dramatically between 1500 and 1630 hours on the day of the survey. The counts increased, in the period of an hour and a half, by a factor of 10,000. The chlorine data shows that at the time of this increase the residual dropped from 2.0 to 0.10 mg/l, indicating a large increase in chlorine demand. Similar low residuals found earlier were associated with coliform counts in the boil of less than 1000/100ml.

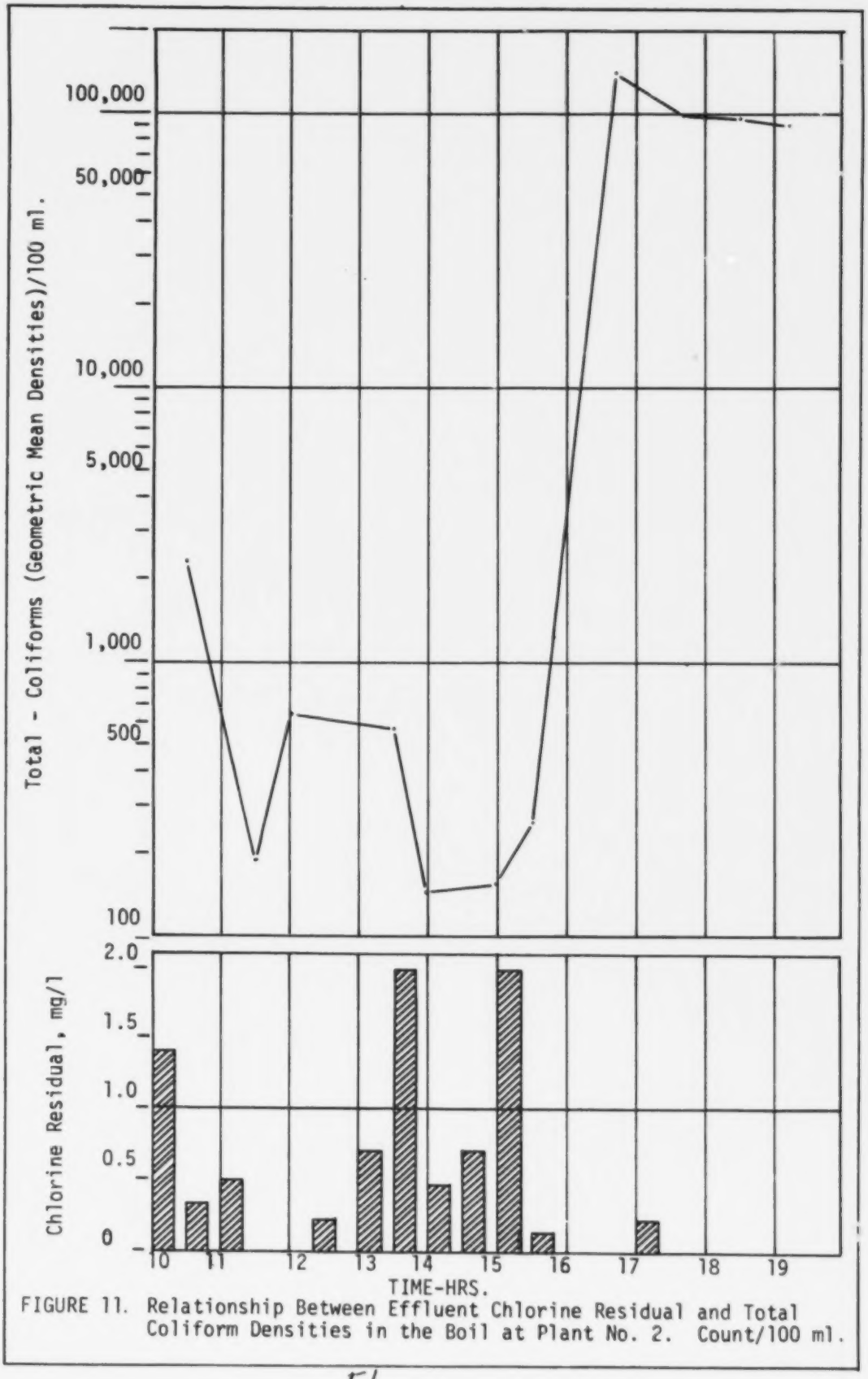

FIGURE 11. Relationship Between Effluent Chlorine Residual and Total Coliform Densities in the Boil at Plant No. 2. Count/100 ml.

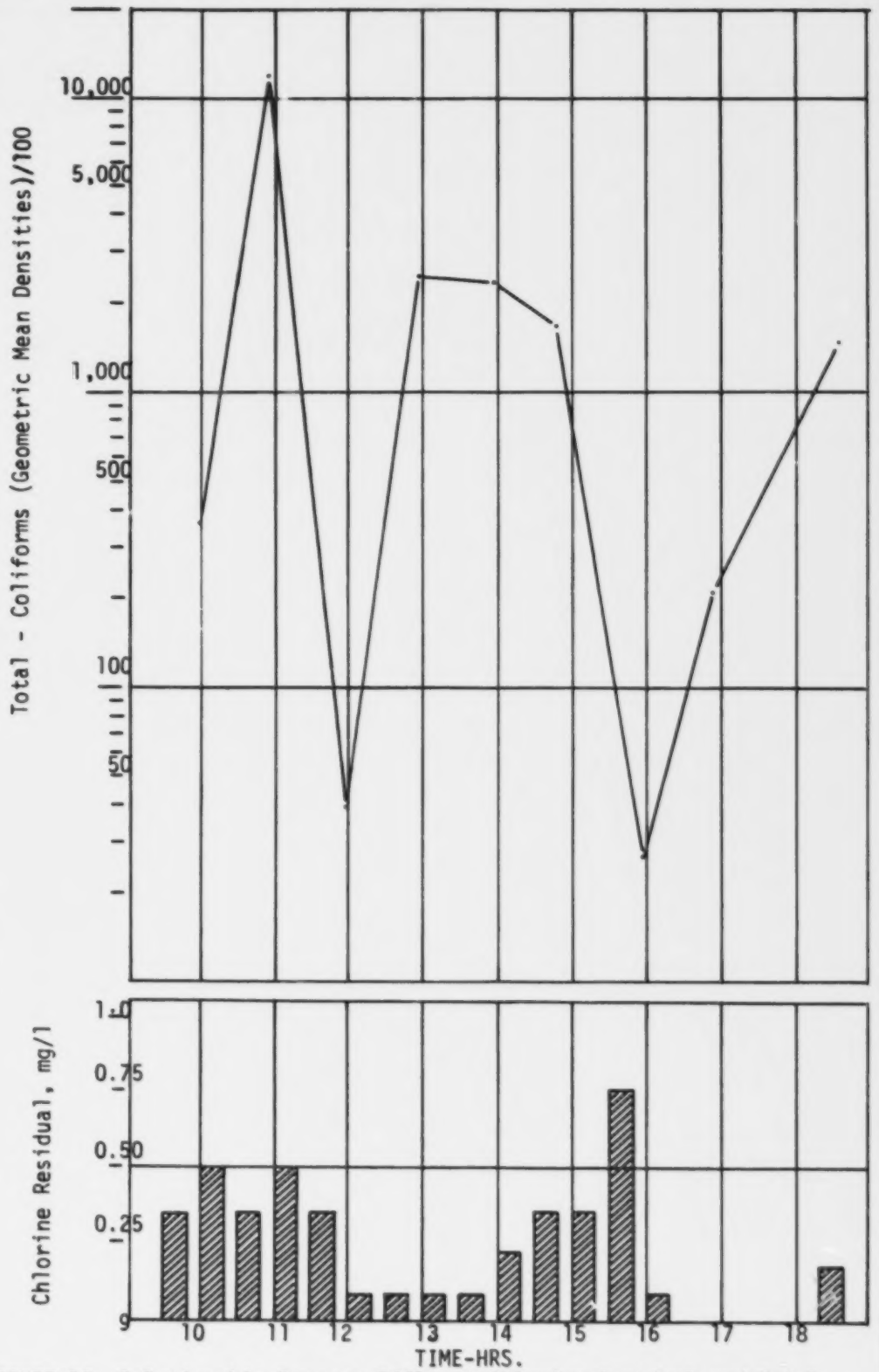

FIGURE 12. Relationship Between Effluent Chlorine Residual and Total Coliform Densities in the Boil at Plant No. 1. Count/100 ml.

Waste Plume Characteristics

The waste plumes from the two Bremerton plants have other important characteristics in addition to variability in waste strength. At Plant 2, the boil (where the waste reached the surface) was clearly visible at all stages of the tide. Small solid particles, paper fragments, etc. surfaced in a concentrated area, due to lack of dilution and dispersion. Numerous sea gulls were frequently observed feeding in the boil. The Plant 1 effluent was visible only briefly during the study. Enough solids reached the surface, however, to provide food for numerous sea gulls. A case has been documented (17) where sea gulls feeding on sewage transmitted enteric diseases to a water supply reservoir.

The waste streams from both outfalls were narrow with sharply defined boundaries in many cases. Once the waste reached the surface and started moving away from the outfall, dilution and dispersion proceeded slowly. Data for the plume sampling at Plant 1 (Figures 9 and 10) show minimum dilutions on the order of 10:1 between the surface boil and points 750 yards down current. This is in an area with significant turbulance and current velocities. The ebb tide plume samples at the Plant 2 outfall, in an area of very low current velocities, showed almost no decrease in coliform levels 600 yards from the outfall. There is little reason to expect that this slow decrease in bacterial concentrations would

change appreciably in the plume beyond the 600-yard point. These data emphasize the importance of (1) obtaining adequate disinfection prior to discharging the wastes through an outfall, and (2) locating and designing the outfall so as to achieve maximum dilution of the wastes. Adequate disinfection is by far the more important of these two factors. If these conditions are not met, the potential exists for the transport of pathogenic bacteria into areas used for shellfish, recreational pursuits, and water supplies.

The problems associated with sampling and evaluating the performance of disposal systems such as these should be recognized. The variability in effluent coliform concentrations requires large numbers of samples at close time intervals to adequately describe the quality of the waste discharged. Another difficulty arises in locating the waste plume. Without the use of dye it would have been impossible to locate the waste field any distance from the Bremerton outfalls. The dye also identified the degree of homogeneity of the waste plume. The plume from the Plant 2 outfall was well defined and continuous from side to side. In contrast, the plume in Port Washington Narrows was not uniform. Patches of dyed effluent and clear water were interspersed. To adequately determine bacterial concentrations under these conditions, large numbers of samples taken almost simultaneously are necessary.

The handling of the digestor supernatant at the Bremerton plants could also contribute to the variability of chlorine residuals and effluent coliform concentrations. The present mode of operation is to pump the solids from the clarifiers to the digestor once a day. The average volume of solids pumped is 2,200 gpd but it varies from 1,500 to 3,000 gallons. As this sludge is pumped into the digestor, a like volume of supernatant is displaced and disposed of directly to the outfall. This supernatant has a high chlorine demand (140 to 160 mg/l) and can have total coliform levels as high as 1,000,000/100ml (16).

A probability analysis of the coliform data from the two plants was made to determine the probable frequency of counts in the boil exceeding 1000/100ml. This analysis was based on the assumptions that the data collected during the surveys were typical and that the data were normally distributed. For Plant 1, the probability of counts at the surface over the outfall exceeding 1000 TC/100ml was 35 to 40 percent. For the Plant 2 outfall, the probability was 60 to 70 percent.

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GLOSSARY OF TERMS

BOD -- Biochemical Oxygen Demand. The amount of oxygen consumed during the biological decomposition of organic material. Measured over a specified time and at a specified temperature.

Chlorine Demand -- The difference between the amount of chlorine added to water, sewage, or industrial wastes and the amount of chlorine remaining at the end of a specified contact period.

Chlorine Residual -- The total amount of chlorine remaining in water, sewage, or industrial wastes at the end of a specified contact period following chlorination.

Digester Supernatant -- The liquid in a sludge-digestion tank which lies between the sludge at the bottom and the floating scum at the top.

Geometric Mean -- The geometric mean is a measure of central tendency (average) which is less affected by extreme values than the arithmetic average. The geometric mean is computed by converting the data into logarithms, averaging the logarithms and finding the antilog of this value.

pH -- The negative log of the hydrogen ion concentration. The pH scale ranges from 0 to 14 with 7 representing neutrality. Acid conditions increase as pH values decrease, and alkaline conditions increase as pH values increase.

Primary Treatment -- The first major process in a sewage treatment works, usually sedimentation. In this phase of treatment a high percentage of suspended matter is removed but little or no colloidal or dissolved matter.

Secondary Treatment -- The treatment of sewage by biological methods after primary treatment by sedimentation.

Standard Deviation -- The standard deviation is a measure of data dispersion. It equals the square root of the average of the squared deviations from the mean.

Surface Boil -- For the purposes of this study, the surface boil is the point at which the wastes from a submerged outfall first reach the surface of the water.

Suspended Solids -- Solids that either float on the surface of, or are suspended in, water or sewage; and which are largely removable by laboratory filtering.

Total Coliform Organisms -- Total coliform organisms are bacteria which are always found in fecal material. The presence of these organisms in water is evidence of fecal contamination, the degree of contamination being proportioned to the total coliform density.

Total Solids -- The solids in water or sewage including suspended and dissolved solids.

Volatile Solids -- The amount of the total solids lost on burning at a specified temperature. This is used as an indicator of the amount of organic material in the sample.